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Temporality, vulnerability, and energy justice in household low carbon innovations

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ABSTRACT

Decarbonisation and innovation will change the affordability of different domestic energy services. This has the potential to alleviate vulnerability to fuel poverty, but it could create new injustices unless the risks are pre-empted and actively mitigated. In this paper, we ask: In what ways can emerging low-carbon innovations at the household scale complement, and complicate, achieving energy justice objectives? Drawing from four empirical case studies in the United Kingdom, the paper highlights different risks that come from different types of innovation required to tackle different decarbonisation challenges. More specifically, it assesses four particular household innovations—energy service contracts, electric vehicles, solar photovoltaic (PV) panels, and low carbon heating—selected for their fit with a typology of incremental vs. radical technology and modest vs. substantial changes in user practices. It shows how in each case, such innovations come with a collection of opportunities but also threats. In doing so, the paper seeks to unveil the "political economy" of low-carbon innovations, identifying particular tensions alongside who wins and who loses, as well as the scope and temporality of those consequences.

1. Introduction

It is becoming increasingly certain that in order to successfully decarbonize the global economy, we must focus on accelerating innovation and technical development across electricity, transport, buildings, agriculture and other sociotechnical systems (Rockström et al., 2017; Geels et al., 2017). However, such technological and infrastructural shifts must also account for necessary and perhaps radical changes to psychology, behavior, knowledge, and lifestyle (Lorenzoni et al., 2007; Gifford, 2011; Stoknes, 2014; Creutzig et al., 2016, 2018). The global decarbonisation challenge becomes even more pressing when one considers that, despite having clear social co-benefits such as displaced pollution and reduced climate change, it still raises pressing justice issues related to equity, vulnerability, fairness, and legitimacy (Auld et al., 2014; Sovacool et al., 2016; Jenkins et al., 2018; Partridge et al., 2018). In simpler terms, with great transformation comes great opportunities – for a cleaner, fairer way of life. However, it also presents risks and we will only reap these rewards if we pre-empt problems and act to mitigate them.

The United Kingdom (UK) in particular offers a paradigmatic example of both the challenges involved in decarbonisation and the potential benefits in overcoming them. National industrial strategy, announced in 2018, calls on all "new cars and vans" to be effectively zero emission by 2040, and for commercial and residential energy use in buildings to be cut by 50% by 2030 (May, 2018; BEIS, 2017a). To meet the carbon targets set out in the Climate Change Act (2008), the UK needs to effectively eliminate the 20% of CO_2 emissions that come from how households use heat and hot water (CCC, 2014). UK homes are plagued by drafts, damp, mold and overheating (even in winter). Around two-thirds of households report at least one of these problems, and many endure such problems to avoid the hassle, disruption and resources required to tackle them (Lipson, 2017). Furthermore, as with other services, when households are in vulnerable situations they can face serious difficulties affording adequate energy, with approximately 4 million UK households classified as fuel poor (BEIS, 2017b; National Energy Action, 2017).[1] Common life events – like childbirth, illness and retirement – can force people to heat their home for longer periods and to higher temperatures, increasing their expenditure on energy, at a

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[1] Fuel poverty is a devolved issue in the UK and each nation has its own definition. Stated figures were 2.5 million in England, 748,000 in Scotland, 386,000 in Wales and 294,000 in Northern Ireland, though fuel poverty was defined in different ways in each country (BEIS, 2017b, p.74).

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time when their incomes decline (Büchs et al., 2018).

Transforming household energy systems via low carbon innovation could present opportunities to improve experiences of using energy. Nonetheless, it also risks exacerbating current problems, or creating new problems for households if it is conducted without considering the unintended consequences of the transformation. For example, policymakers might be able to harness digital platforms and smart meter data to target support at households who are vulnerable to fuel poverty (Sovacool et al., 2017a). However, some households may be harmed by new digital energy business models, such as homes without the internet, or by carbon taxes, such as homes without access to low carbon energy networks.

In sum, both the global and domestic decarbonisation challenge in the UK require transformational changes that can disrupt the energy system, and related energy practices, as we know them. To assess issues of fairness and vulnerability in this complicated and shifting landscape, this paper asks: In what ways can emerging low-carbon innovations at the household scale complement, and complicate, achieving energy justice objectives? This paper highlights different sorts of risk that come from different types of innovation required to tackle different sorts of decarbonisation challenge. More specifically, it assesses four particular household innovations—energy service contracts, electric vehicles, solar PV, and low carbon heating—selected for their fit with a typology of incremental vs. radical technology and modest vs. substantial changes in user practices. It shows how in each case, such innovations come with a collection of opportunities but also threats and risks. In doing so, the paper seeks to unveil the "political economy" of low-carbon innovations, identifying tensions alongside particular winners and losers.

So far, research exploring the political economy of energy justice, such as Healy et al. (2019), Jenkins et al. (2016a), Baker et al. (2014), and Newell and Mulvaney (2013) has tended to examine sources of energy supply such as nuclear power or coal, and/or developing countries. Other work emphasizing tradeoffs has focused on energy security (Sovacool and Saunders, 2014) or the sustainable development goals (Fuso Nerini et al., 2017). This paper will build on the small amount of work (Lambie et al., 2016; Gillard et al., 2017) that has looked at energy justice, political economy or tensions—the achievement of one justice dimension at the expense of another—at the household scale in an industrialized country such as the UK. This paper highlights that "low carbon" does not mean a positive outcome for all consumers. We already see certain groups underrepresented in discussions and policymaking, such as those in fuel poverty (Gillard et al., 2017), implying that a low carbon system will not necessarily improve access to affordable energy.

To make this case, the paper proceeds as follows. It first explains its research methods and selection of four case studies from a typology of low-carbon innovations. Included in this section is also a brief introduction to the concept of energy justice. Then, the paper examines intently the justice tensions across energy service contracts (incremental innovation with a substantial change in user practices), electric vehicles (radical innovation with a substantial change in user practices), solar PV (radical innovation with modest change in user practices), and low carbon heating (incremental innovation with modest change in user practices). It concludes with broader implications for planners, policymakers, and researchers.

2. Research concepts, methods and case selection

To begin, we selected four different classes of technology (to serve as case studies of low carbon innovation) fitting into a modified typology presented by Geels et al. (2018). As that typology in Fig. 1 indicates, innovations can be technologically incremental (such as loft insulation or quieter washing machines) or radical (such as battery electric vehicles or LED lights). They can also require only a modest change in user practices (such as fuel economy improvements to conventional cars or gas boilers) or a substantial change in user practices (living in passive houses, adopting teleconferencing or e-working rather than commuting to an office).

We selected this typology because it has at least four strengths. It was explicitly designed for the topic of low carbon transitions and innovations. It expressly suggests that a low carbon transition is not solely a techno-economic matter, but a social or socio-technical one involving users and changes in practices, consumption, and demand. It forces analysts to be comprehensive when examining energy justice issues, calling attention not only to radical or transformative new technology but also to more mundane and conventional ones that reinforce conventional practices (or systems). Lastly, it implicitly recognizes a temporality to innovations, that over time they may move between the quadrants as their performance attributes change or consumers adjust their practices.

We selected innovations, or technological case studies, that fell within each quadrant of this typology. These are:

- Energy services contracting, an example of a technologically incremental innovation requiring substantial changes in user practices (e.g. buying a warm home rather than units of fuel);
- Electric vehicles (EVs), an example of a technologically radical innovation requiring a substantial change in user practices (e.g. how they are refueled and charged, adjustment of range and trip length);
- Solar photovoltaic (PV) panels, an example of a technologically radical innovation requiring little or modest changes in practices (e.g. electricity supply is still reliable);
- Low carbon heating, an example of an incremental innovation requiring a modest change in user practices (e.g. reliable heat supply).

Methodologically, such an approach has been described as "comparative cross case analysis," ideal for testing or confirming a hypothesis and examining causal effects beyond a single instance (Gerring, 2004, 2005; Seawright and Gerring, 2008). The aim of discussing the energy justice implications across four different cases is to highlight how widespread the potential issues are, so that there is a stronger focus on designing a transition that is fair or just. We maintain that this will not happen automatically without explicit attention. Although we examine only four cases qualitatively, we maintain that such a small number of cases can still result in qualitatively "big conclusions" (Lieberson, 1991). The study thus attempts to achieve what Yin (2014) terms *analytical* (not statistical) generalization. Rather than drawing inferences from statistical data to a population, it instead makes projections about the likely generalizability of findings based on a qualitative analysis of factors and contexts.

To collect data on these four case studies, we conducted a narrative, thematic review to look for qualitative evidence across the four innovations. We searched for peer-reviewed studies indexed on the Scopus database with repeated searches across journals in the domains of energy and buildings, energy policy, mobility and transport policy, innovation studies, sustainability transitions, geography, and political science. We searched only in English, and were looking for only the most recent evidence, i.e. studies generally published within the past five years. We collected approximately seventy studies and cite most of them in the results section.

Lastly, as a conceptual lens through which to filter all of this data, we relied on the emerging concept of "energy justice." Generally, Sovacool et al. (2016) write that this framework demands a focus on:

- Costs, or how the hazards and externalities of the energy system are disseminated throughout society;
- Benefits, or how the ownership of and access to modern energy systems and services are distributed throughout society;
- Procedures, or ensuring that energy decision-making respects due process and representation;
- Recognition, or assessing the impact of energy systems on the poor,

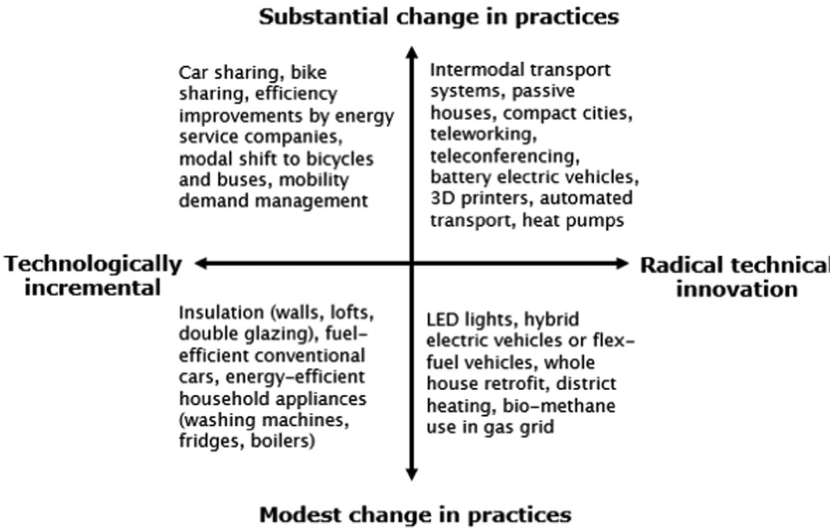

Fig. 1. A typology of low-carbon innovations. Source: Modified from Geels et al. (2018). Geels et al. (2018) had originally placed electric vehicles in the bottom right quadrant—we have made that category of vehicles more explicit by placing hybrids in the bottom right but full battery electric vehicles, or BEVs, in the upper right. We have also placed heat pumps in the upper right given in the UK users have struggled to adjust their practices when adopting them.

vulnerable, or marginalized.

To operationalize energy justice in practice, Sovacool et al. (2017b) and Delina and Sovacool (2018) stipulate the ten energy justice "principles" for decision-makers shown in Table 1. Jenkins et al. (2016b) similarly frame energy justice as relating to the "what," "who," and "how" of social justice. The "what" relates to distributive justice and involves describing where issues are located and how they might be solved. The "who" concerns recognition and who is ignored, and how they ought to be empowered or recognized. The "how" concerns procedures and mechanisms to ensure injustices are addressed and new decisions are fair.

Within the energy justice literature, a stream of research has emphasized "political economy" (broadly meant to convey winners and losers) or the tensions between pro-justice (and often low carbon) interventions or efforts. As Sovacool et al. (2017b:680) write:

> Sometimes or perhaps even often, energy justice issues do not exist in black or white – there is no single, or even identifiable, immediate "winner," nor an immediate, discernable "loser." Instead, there are bundles or constellations of winners and losers, and even "pro-justice" interventions can create some type of inequality, even when they offer net societal benefits.

A community attempting to provide universal access to energy, for instance, would harness its fossil fuel resources as quickly as possible (meeting justice standards of equity), but in doing so would erode the natural resource base (violating principles of sustainability as well as futurity, as fewer resources would be available for future generations).

This paper will argue that using such a conceptual lens to explore a changing household energy system can reveal potential threats and opportunities for how a transition might affect issues of equity and justice. All too often it is assumed that tackling climate change and addressing fuel poverty are mutually synonymous, or these issues are left unconsidered completely. Moving away from the inherently politically contested concept of "fuel poverty" in the UK, we free ourselves of the trappings of the current system and the current definition of who is or is not fuel poor. The energy justice framework allows the focus to be broader than much of the previous work that has only explored distributional justice and will build on recent work that engages with broader understandings of what drives inequalities and injustices for energy consumers (e.g. Simcock and Mullen, 2016; Gillard et al., 2017; Robinson et al., 2018).

The potential for such energy justice tensions to exist is not academic. We see them empirically with numerous examples around the world, ones involving not only fossil fuels and nuclear energy but low carbon innovations such as wind power, solar energy and EVs. Efforts to alleviate energy poverty in China and India have involved an expansion of coal-fired power that, in tandem, has resulted in an increase in the mining of coal, some of which is done by child laborers, and/or rising rates of pneumoconiosis, or black lung disease (Sovacool et al., 2017b). Landfills and waste-to-energy facilities in Scotland, and nuclear storage facilities in Taiwan, have met principles of availability and sustainability, but violated those of equity, due process, or fairness (Walker, 2012); similar tensions have occurred at nuclear power facilities in Japan and South Korea (Park and Sovacool, 2018). The production of Canadian tarsands has met the principles of availability and

Table 1
Ten energy justice principles.
Source: Modified from Sovacool et al. (2017b: 687) and Delina and Sovacool (2018).

Principle	Explanation
Availability	People deserve sufficient energy resources of high quality.
Affordability	All people, including the poor, should pay no more than 10% of their income for energy services.
Due Process	Countries should respect due process and human rights in their production and use of energy.
Transparency and accountability	All people should have access to high-quality information about energy and the environment and fair, transparent, and accountable forms of energy decision-making.
Sustainability	Energy resources should not be depleted too quickly.
Intragenerational equity	All people have a right to fairly access energy services.
Intergenerational equity	Future generations have a right to enjoy a good life undisturbed by the damage our energy systems inflict on the world today.
Responsibility	All nations have a responsibility to protect the natural environment and minimize energy-related environmental threats.
Resistance	Energy injustices must be actively, deliberately opposed.
Respect	Intersectional differences in knowledge and epistemic upbringing, culture and experience, and race and gender have to be respected in energy decision-making.

affordability, but done so by displacing and damaging vulnerable groups of indigenous peoples (Walsh and Stainsby, 2010). Wind farms being constructed and operated in Mexico have perhaps enhanced the principles of availability and sustainability, but done so at the erosion of due process, transparency, and community equity (Oceransky, 2010). Solar energy parks in India have similarly sought to enhance availability of energy and sustainability, but done so through exclusion, land grabbing, and elitism (Yenneti et al., 2016). Sovacool et al. (2019) also demonsrated that EVs in the Nordic region promoted aspects of sustainability and responsibility, but at the expense of affordability and equity.

In sum: energy justice does not exist in a vacuum, and this body of work strongly suggests one must always be cognizant of the socio-economic tensions that can occur when attempting to transition energy or transport systems.

3. Results: energy justice and low-carbon household innovation in the UK

It is with this appreciation for both energy justice and the pernicious potential for tensions that we examine four specific technological case studies of low carbon innovations at the household scale in the UK. When considering the energy justice framework more explicitly, we examine four principles in greater depth:

- Affordability, meant to include the cost of the innovation and whether it can provide comparatively inexpensive energy services that most households can afford;
- Sustainability, meant to capture the improved efficiency or environmental performance of an innovation, including greenhouse gas mitigation;
- Equity, meant to capture the accessibility of an innovation to ordinary households, as well as potentially future generations;
- Respect, meant to ensure that an innovation does not impose burdens on particular demographic groups, especially vulnerable groups.

As a high-level summary of our qualitative assessment, Table 2 shows how every innovation meets some justice principles at the expense of another. Some, as we will see, even conflict internally, such as the sustainability attributes of EVs, or the affordability of low carbon heat.

3.1. Energy service contracting

Energy service contracts illustrate tensions between affordability and sustainability (by giving consumers more confidence they will get the outcomes they want from using energy, whilst expending less effort or money) and equity and respect (potentially only benefitting those who are offered contracts).

Energy services contracts, as with other services, enable consumers to buy the outcome they want (e.g. a warm building), rather than having to assemble, integrate and operate all the components needed to deliver it (e.g. fuel, a heating system, heating controls). Economic forces drive service providers to discover more efficient ways to deliver higher quality services, so that they can reduce their costs and increase the value they offer their customers. Emerging connected home technologies, or smart home technologies (Wilson et al., 2017), can create data sources that catalyze opportunities to broaden the scope and range of such contracts significantly. Energy companies could rely on digitalization and information technology to extend personalized energy services to domestic consumers.

Table 2
Qualitative energy justice assessment of four low-carbon domestic innovations. Source: Authors. Pluses qualitatively indicate the justice principle is strengthened, minuses that it is weakened, the number of marks indicates the degree (one mark is slightly, two is moderately, three is strongly).

	Energy service contracting	Battery electric vehicles	Solar PV panels	Low carbon heat
Affordability	+ + +	–	+	+/–
Sustainability	+ +	+/–	+ +	+ + +
Equity	– – –	– – –	– – –	–
Respect	– –	–	–	–

Over the past few decades, energy service contracts have become a more prominent mechanism for encouraging non-domestic consumers to implement efficiency measures related to either electricity use or heat (Nolden et al., 2016). Usually, an energy service contract guarantees a specific level of energy service over several years, with the cost of the energy efficiency measures being financed by the energy they save. The idea is that such an approach can overcome the usual barriers to energy efficiency by reducing transaction costs and better managing risks (Nolden et al., 2016; Nolden and Sorrell, 2016). A novelty here is also focusing not on energy technology per se or the value proposition of selling commodities and fuels such as gas or electricity, but instead the energy service itself such as light, warmth, or hot water (Brown, 2018; Fell, 2017). In their overview of the UK energy service contract market, Nolden and Sorrell (2016) note that the business model for performance contracts was imported from the United States in the 1980s, and grew in the 1990s driven partly by the diffusion of combined heat and power and partly by the growth of facilities management contracts. As of 2014, when Nolden and Sorrell (2016) collected their data, the energy service contracting market was populated by dozens and dozens of firms, many of them "large players," with a range of origins and actors summarized by Table 3.

Early experiments show that households like the idea of buying a warm home rather than units of fuel (Lipson, 2018). This opens up a new route to decarbonizing heating. If energy service providers were mandated to decarbonize over time, like car manufacturers, businesses that learnt to design and deliver appealing low carbon domestic energy services could reap significant commercial rewards (Batterbee, 2018). In theory, Lipson (2018) notes that various positive possibilities emerge: service providers can form richer relationships with their customers, reducing the costs of acquiring and retaining them and offering higher value services; device vendors can apply usage data to improve their products and share the value their devices deliver; network operators and investors can work with service providers to plan network upgrades that consumers will want to pay for, as providers will understand what consumers need from complex energy infrastructure.

However, the expansion of energy service contracts also brings with it justice risks. Cirell (2016) warns that not all energy service companies are equal. Some, such as those devolved to or controlled by local authorities, may try to mitigate fuel poverty. But others, especially at for-profit firms, may actually discriminate against customers who will produce lower profits. Hannon and Bolton (2015) found the for-profit versus non-profit distinction to be important in their survey of local authorities in the UK and the energy service companies they promoted. As Hannon and Bolton (2015: 206) warned, commercial energy service providers "will tend to prioritize projects that promise high returns, such as large scale, mix-use schemes with strong economies of scale and a balanced demand load, over smaller projects that may promise lower returns but with a stronger environmental and/or social welfare dimension." This same profit motive could also lead domestic energy service providers to focus on attracting more "desirable" (i.e. more profitable) customers, leading to different implications for different consumers (OFGEM, 2017).

Indeed, issues of justice, equity, and privacy remain heavily debated and contested in public and media discussions in the UK (Milchram et al., 2018; Hielscher and Sovacool, 2018). Those households in vulnerable situations, especially the chronically poor, and on low incomes are unlikely to be able to engage with new services as early and as

Table 3
Energy service contracting market in the UK.
Source: Modified from Nolden and Sorrell (2016).

Origin	Main companies
Equipment suppliers	Doosan Babcock, Finning, General Electric, Honeywell, Johnson Controls, Philips Lighting, Siemens, Veolia (Dalkia)
Utilities and energy suppliers	EDF, E.On, British Gas Business, SSE
Construction and engineering companies	Bilfinger, Bouygues, Imtech, Interserve, Kier, Skanska, Wilmott Dixon
Facilities management or integrated services	Carillion, Cofley, ENERG-G, Mitie, Norland, Schneider Electric
Procurement agencies	EuroSite Power, Utilitywise
Independent ESCOs	Ameresco, Anesco, Breathe Energy, Cynergin, Self Energy, Utilyx, Vital Energi
Local authorities	Aberdeen Heat and Power Company, Barkantine Heat and Power Company, Birmingham District Energy Company, Coventry District Energy Company, Enviroenergy, Leicester District Energy Company, Pimlico District Heating, Southampton Geothermal Heating Company, Thameswey Energy
Communities	Brighton and Hove Energy Services, Douglas Community EcoHeat, Kielder Community Enterprises, Meadowside Ozone Energy Services, Ovesco, Woolhope Woodheat

comprehensively as other households. Those groups suffer from the "poverty premium" whereby the poorest pay more for essential goods and services, for instance because they live in rented accommodation or have poor credit ratings (Cambium Advocacy, 2015; Davies et al., 2016). The group most highly exposed to the poverty premium was defined by using prepayment meters for fuel and using higher-cost financial credit (Davies et al., 2016). As such, people without access to a smart new world of energy services could become the *new* fuel poor. Anyone without access to the internet, tenants unable to install sensors or sign up to contracts, anyone without a smart phone, or groups deemed undesirable by providers (for whatever reason) could all be excluded.

However, Lipson (2018) has highlighted that services could also create new routes for policymakers to deliver societal goals, like tackling fuel poverty. Service providers would have to learn how much it costs to deliver their service to households, but there would be no need for consumers to pay if they could not afford it. For example, government subsidies could be used to pay service providers by results (such as improving affordability of specific levels of energy service) rather than based on outputs (such as the number of homes that have been insulated). Service providers would have a commercial incentive for delivering energy services as efficiently as possible, encouraging them to find the best mixture of fabric and appliance efficiency in each home.

3.2. Battery electric vehicles (EVs)

Battery electric vehicles, hereafter electric vehicles (EVs), underscore the tensions between sustainability (displaced carbon, reduced urban air pollution) and affordability and equity (only particular groups can afford to purchase or use them).

For example, EVs can result in lower total emissions, particularly when compared to other alternatives (Reddy et al., 2016). The environmental and climate change benefits of EVs can vary considerably by context, but generally emit less greenhouse gas than conventional vehicles, with estimates ranging from 10–24% (Hawkins et al., 2013) to 62–65% (Addison et al., 2010). Climate change benefits can accrue via the electrification of transport, controlled charging to avoid high carbon electricity sources, decarbonisation of the ancillary service markets, or peak shaving of high carbon electricity sources. For instance, numerous studies in the literature suggest that EVs generally operate more efficiently than those that run on internal combustion engines, given the comparative efficiency of electric drivetrains (Tran et al., 2012; Mitchell et al., 2010). Other broader social co-benefits of EVs include displaced urban air pollution and improved public health; von Stackelberg et al. (2013) for instance calculated that gasoline passenger vehicles cause $26 billion in health damages annually in the United States. Nonetheless, the ability of different low carbon transport policy approaches to address issues of justice and equity is unclear and can affect different groups differentially, resulting in a more or less just system (Mullen and Marsden, 2016; Mattioli, 2016).

In the UK, EVs could be an ideal option for those who can afford a newer vehicle and a home with off-street parking who do not need to drive far (perhaps people living in urban/suburban areas with good public transport options, or in good to moderate health so they can walk to where vehicles are parked). Currently, in the UK the cost of the vehicles is subsidized (by taxpayers) and the cost of the fuel is cheaper because EV owners do not have to pay VAT on electricity.[2] Projections suggest that EVs could cut emissions from passenger transport in the UK in half, from roughly 32 t of carbon dioxide to 15 t of carbon dioxide for smaller vehicles across their lifecycle (from construction to use and scrapping) (Gabbatiss, 2018). Similarly, assumptions made in the modeling done for the Committee on Climate Change suggest that "the CO_2 emissions of a vehicle are reduced by 50% if it has an electric range of 25 km" in the UK (Stewart et al., 2015: 14).

However, EVs could benefit some people more than others. Consider that access to mobility in the UK is not equal. Car access, distances travelled, and income are all closely and positively correlated (Offer et al., 2011). Wealthier households drive more frequently, drive further distances, and have a greater ability to purchase new cars. Using vehicle test records, patterns of car usage, and energy consumption data, Chatterton et al. (2018) find that UK motoring costs are strongly regressive, with lower income areas, especially in rural locations, spending about twice as much of their income on mobility as the highest income areas. Wells (2015) notes in particular that half of all UK households in the lowest 20% by income did not have access to any sort of car whatsoever, and that many of these households were also composed of vulnerable groups such as the disabled, the elderly, or single parent families.

Thus, consumers who cannot afford to buy a new EV may end up paying more to run an older, less efficient petrol or diesel car. Approximately one third of people in the UK live in homes without off-street parking, of those around half struggle to park in the same place every night (ETI, 2013). They may face higher costs to install charging infrastructure and higher non-monetary costs finding a place to charge their car. Furthermore, as EV uptake rises, there will be commercial pressures on fuel stations to close as they begin to service fewer customers, which could make it more time-consuming and expensive to fuel a petrol or diesel vehicle.

There is even the potential for the poor to provide financial support for the affluent. Historically, Lane and Potter (2007) note that most

[2] Further detail on VAT available at https://www.gov.uk/guidance/rates-of-vat-on-different-goods-and-services#power.

adopters of EVs in the UK have been new car purchasers, with high educational levels and incomes, who reside in urban areas. Wells (2015: 23) emphasizes that the automotive industry considers this to still be true, quoting one expert who said:

> These [EV] customers are predominantly high-earning, environmentally aware city dwellers who already own a premium vehicle. They said they would use the e-car mainly as a second or third car, mostly for short trips. This group of customers, which we call the "Premium 2.0" segment, is not price sensitive in that by buying an environmentally friendly e-car they can be seen to be green.

By contrast, lower income households tend to purchase cheaper and less-efficient vehicle models (ONS, 2017). This means they could end up paying to subsidize EVs without being able to benefit from the lower running costs.

Even the environmental sustainability benefits of EVs in the UK are contested, and can be eroded by rebounds or unsustainable practices. Graham-Rowe et al. (2012) noted for example that because adopters perceived their EVs to be more "environmentally-friendly," they drove them 1.64 times further than cars they did not see as "eco-cars." Some drivers even attempted to recharge their vehicles not by plugging in at home or at work, but by running the internal combustion engine and then using the re-generative braking system to "charge" their vehicle "thereby negating the carbon savings" (Graham-Rowe et al., 2012). Modeling of EV driving behavior (Hamamoto, 2019) also underscores this paradox: EVs are more technically efficient than conventional cars, meaning they have great carbon abatement potential, but if/when adopters increase their annual mileage, overall emissions for transport can actually increase.

Moreover, the limited range of EVs could present higher risks to those who live in more remote locations, where they will likely have to travel further for work or to access supermarkets and other services. Alternatives to car ownership, like car clubs, autonomous cars or taxis are more difficult in remote areas because of the lower demand, and could therefore cost more. EVs can lastly shift pollution flows from urban areas (tailpipes) to rural areas (power plants). Offering partial support for this claim, Woodcock et al. (2009) noted in London that reduction in traffic or the phasing in of cleaner modes of mobility (such as EVs) had the greatest health benefits in urban areas, but negligible impacts on rural areas, making benefits unevenly distributed.

3.3. Solar photovoltaic (PV) panels

Installing household solar photovoltaic (PV) panels brings a host of benefits, including displaced fossil fuels and the opportunity to take advantage of feed-in tariffs, but also raises concerns related to equity and affordability.

Solar PV panels are a source of electricity that can be built in various sizes, placed in arrays ranging from watts to megawatts, and used in a wide variety of applications, including for homes, integrated into buildings, or even for off-grid systems for remote power use. PV systems have emerged to be a modular and generally durable source of electricity. In the UK, about one million households (or 3% of all homes nationwide) have installed solar PV panels and two-thirds of them were using them for self-generated power (Strielkowski et al., 2017). KPMG (2015) argued that these trends made the UK "the most dynamic PV market in Europe" at that time with PV "becoming the most popular renewable energy among British electricity consumers".

On the positive side, people who put PV on their roofs can generate their own electricity, saving money and earning from feed-in-tariffs for electricity they sell back to the grid. They may benefit more if they can store electricity in a battery or hot water tank to use when they need, especially if households begin to face time of use tariffs (Infield, 2007; Barnham et al., 2012; Parkhill et al., 2013; Uddin et al., 2017). BEIS (2016) suggest that solar PV will be significantly cheaper by 2020 than predicted three years ago, meaning it could reach a broader range of households. Uddin et al. (2017) even go so far as to argue that if current battery cost reduction trends persist, then households with solar PV could ultimately disconnect from the grid, leading to autonomous homes or micro-grids. Lastly, there is the potential for solar PV to increase reliability for consumers when the main electricity supply isn't available, such as during power cuts and maintenance. This can be especially important for households where constant electricity supply is important, such as those who are reliant on electricity for medical equipment like a stair lift, nebulizer or refrigeration to preserve medicine. This type of vulnerability is already acknowledged by the Priority Services Register in the UK.[3]

Strikingly, however, the benefits of existing solar PV are not evenly distributed. Indeed, household solar PV is exclusionary insofar that adopters need to own a building or a roof. This excludes the 37% of people who do not own their own home (ONS, 2018), or live in flats without a roof. In addition, modeling undertaken by Strielkowski et al. (2017) suggests that solar PV in the UK favors richer consumers and particular network users who do not bear their fair share of total system distribution and transmission costs. They warn that any increase in solar PV in the UK only comes at the risk of further transfers of wealth between lower income and higher income consumers, given that feed in tariffs for solar PV are paid for by a levy on energy bills by all consumers. Under the current scheme, this is potentially regressive, because energy costs account for a larger portion of bills for lower income households than those that are better off. Below average income households therefore pay more for energy policy costs, as a percentage of their share, than richer households (Barrett et al., 2018).

But the risks to justice are not just about the income of consumers. As a substantial piece of technology in the home and from a relatively new retail sector, consumers need information and knowledge in order to make a choice to purchase and use solar PV equipment. This is a problem to all consumers but is most significant to those without access to the internet, with poor health, previous financial difficulties and lower education levels (Walker, 2008). Finally, solar PV gives rise to some negative externalities, including toxic materials utilized during manufacturing and installation, required integration with other systems, and dependence on rare earth mineral imports that do have global whole-systems impacts outside of Europe (Sundqvist, 2004; Burger and Gochfeld, 2012).

3.4. Low carbon heat

As a final example, investments in low carbon heating—changing fuels, heating systems and/or perhaps improving thermal efficiency—can reduce greenhouse gas emissions and improve the long-term livability of homes but also raise issues of sustainability and futurity.

Today in the UK, most homes burn natural gas in boilers to get heating and hot water. Tackling climate change means heating these homes with something other than natural gas. Various analyses highlight a significant role for electric heat pumps, district heat networks, or repurposing the natural gas grid to transport hydrogen or biogas instead (BEIS, 2017b). Such efforts are sometimes—though not always—complemented with building thermal efficiency improvements such as insulation.

Most buildings that will be standing in 2050 have already been built so the decarbonisation challenge for heat is one of retrofitting, not necessarily new build. Well insulated homes require less fuel to heat, can be heated by lower power heating systems (like heat pumps), warm up quicker, stay warm longer, and may be less likely to become damp. Upgrading buildings with new heating systems or insulation can also

[3] See https://www.ofgem.gov.uk/consumers/household-gas-and-electricity-guide/extra-help-energy-services/priority-services-register-people-need.

raise the value of the property (DECC, 2013).

However, heating improvements require capital investment. This presents difficulties to people without the capital, or who do not own their own home. Policies may be introduced to encourage households to switch away from natural gas central heating. Penalties such as a carbon tax on natural gas, or boiler prohibition would penalize those unable to afford an alternative. Subsidies designed to reduce the cost of low carbon heating would not help those without access to suitable alternatives. After all, it will take time to upgrade electricity networks, construct heat networks, or repurpose the gas grid, so some households will have no access to low carbon energy networks during the transition.

Furthermore, some particular low-carbon heating technologies, such as heat pumps, can backfire for households, especially lower income households. Hannon (2015) notes that in the UK, 3.6 million homes are unconnected from national gas grids, and require central heating, which might make them more suited to heat pumps. However, early trials with heat pumps suggest not only that some had frequent faults, but also that occupants had to learn how to use them effectively (Sweetnam et al., 2018). Some suffered "periods of high electricity bills," entrenching dissatisfaction and also worsening "fuel poverty in this vulnerable segment of the population" (Lowe et al., 2017: 139).

In addition, when fuel switching away from gas is coupled with efficiency improvements, such efforts can be mitigated by rebound/takeback effects, or poor quality work. In some cases, the Warm Front program in England, which installed more efficient boilers and/or insulation in more than 2.3 million homes, saw net household energy consumption paradoxically increase after the implementation of efficiency upgrades (Sovacool, 2015). Looking at a subsample of Warm Front homes, Hong et al. (2006) and Green and Gilbertson (2008) both noted that some households "took back" the benefits of improved energy efficiency as increased warmth and comfort rather than as fuel savings particularly following the installation of a new heating system. This essentially meant such homes achieved improved comfort at the expense of societal goals to reduce emissions. And, when looking at the community of heat installers in the UK, Wade et al. (2016) also noted a series of "bad practices" including "examples of poor workmanship of varying severity, from messy pipes, poor finishes and incorrect locations to unsafe, illegal installations." This harms the very homeowners who took the diligence to implement low-carbon heating improvements.

4. Conclusion and implications

To conclude, our analysis does reveal that transforming the UK household energy system creates a bounty of desirable opportunities as well as complex tensions and risks that need to be managed actively.

Low carbon innovations in the household sector have immense opportunity to deliver positive co-benefits. The adoption of energy service contracting can generate financial savings. EVs can reduce carbon emissions and air pollution. Solar PV can reduce household energy bills and also lead to added revenues from feed in tariffs. Retrofitting homes with low carbon heating can improve indoor air quality and improve property values. When coupled with emerging innovations such as smart home technologies or storage, the benefits could become synergetic. A world of energy services could for instance reveal new routes to eliminating fuel poverty, or culminate in new integrated business models centered on whole-systems decarbonisation (including appliances and cars within homes but also connecting homes to each other or low-carbon urban networks). In this way, each of the low-carbon innovations examined can enhance some aspect of energy justice. In particular, those owning homes or seen as "desirable" customers seem to have some of the best potential for capturing the benefits of low-carbon innovations.

However, decarbonizing the household energy system also comes with justice tensions. As Table 4 summarizes, each of the gains

Table 4
Summary of household low-carbon innovation justice tensions.
Source: Authors.

Case study	Technological complexity	Change in user practices	Positive justice dimensions	Negative justice dimensions
Energy services	Incremental	Substantial	Cost savings, more reliable service, more predictable cost, increased productivity of subsidies	Some may be excluded from the market (e.g. because they lack the internet, sensors or a smart phone)
Electric vehicles	Radical	Substantial	Reduced carbon emissions and air pollution, fuel savings	Less accessible to those without off-street parking, and/or those who cannot afford a new car
Solar photovoltaic panels	Radical (especially with storage and time-of-use tariffs)	Modest	Reduced electricity bills, improved resilience and potential revenue from feed in tariffs	Limited to those who own their own roof but subsidized by everyone and too difficult for some to understand
Low carbon heat	Incremental	Modest	Upgrading heating systems and insulating homes can raise property values and improve the quality of indoor environments	Some lack the capital to invest in upgrades or the ability to make the decision because they rent their home

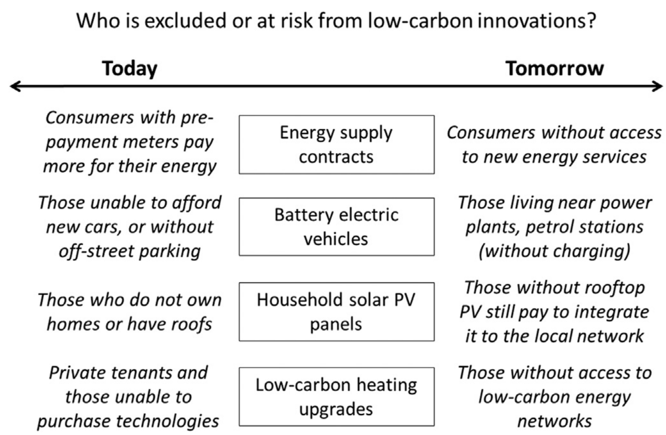

Fig. 2. Differentiating current from future justice challenges. Source: Authors.

mentioned above come with a collection of risks. These risks especially concern the potential for energy justice principles such as affordability and sustainability to erode equity and respect. Those without the internet, sensors or a smart phone may have less access to future energy service contracts. Those unable to afford an EV or park it off the street may pay more for less convenient transport. Those who cannot generate their own electricity because they do not own their own roof, cannot afford PV, or cannot comprehend the technicalities, may miss out on lower energy bills, even though they pay to subsidize them. Those who cannot upgrade their heating to low carbon alternatives because they lack the capital or live in poorer quality, lower value housing could be penalized by measures to reduce household carbon emissions. In particular, those not owning their own homes may miss the opportunities to benefit from low-carbon innovations. Conceptually, these findings remind us, too, that even innovations with only incremental technological complexity (energy services, heat) as well as modest changes in user practices (solar PV, heat) can still result in qualitative injustices alongside radical innovations or those requiring substantial changes in user practices. In this way, the conservative or incremental attribute of an innovation is independent of whether it can contribute to energy injustice.

There is also a temporal dimension to the justice dimensions we examine—injustices occur not only in space (across different scales or actors), but also over time (as Fig. 2 indicates). Currently, energy service companies may prefer only those projects with the greatest rates of return, excluding smaller projects. As energy service contracting markets grow in the future, however, exclusion could shift to those that refuse to participate in the digital economy or those that resist smart home technologies. Current EVs are often unaffordable for those not able to purchase new cars or without accessing to off-road parking. In the future, if adoption of electric vehicles causes petrol service stations to close, those owning or using petrol or diesel vehicles could struggle to refuel their vehicles. Over time, EVs could also shift pollution patterns from tailpipes to power plants, "cleaning" urban areas at the possible expense of rural areas. Those who do not currently own their own property or have access to a roof are functionally excluded from benefitting from solar PV. However, in the future when household energy prices may vary in real time, then those with solar PV and storage could benefit by storing electricity when it is cheap and selling it later when prices rise, but those unable to afford the equipment, or unable to shift their consumption patterns, will be worse off. In the domain of heat, currently tenants and those unable to find the capital to invest in heating efficiency are excluded from benefits. In the future, those without access to low carbon heat sources—whether from district heat, repurposed gas networks, or low carbon electricity networks—may be penalized if carbon policies increase the cost of using natural gas boilers Fig. 2).

In other words: low-carbon innovations never eliminate risk, they just shift or redistribute it qualitatively, spatially, or temporally. Existing energy policy may be far more focused on the needs of today's poor, rather than tomorrow's. Instead, we must craft policy that is more aware of tensions so they can be minimized or maybe even eliminated. Ultimately, decarbonizing will change the affordability of energy services as well as the desirability and scope of different energy practices. This can alleviate the impact of existing vulnerabilities to fuel poverty and enhance principles of justice, but it also threatens to push people into new forms of poverty and exclusion unless emergent risks are preempted and actively mitigated.

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References

Addison, David, Al-Chalabi, Malek, Elwell, Cliff, Evans, Mark, Salmond, Neil, Saunders, Rob, 2010. Open Roads, Anxious Drivers: A Technology and Policy Assessment for Long Range Electric Vehicles in the UK. Energy Policy Project, London.
Auld, G., Mallett, A., Burlica, B., Nolan-Poupart, F., Slater, R., 2014. Evaluating the effects of policy innovations: lessons from a systematic review of policies promoting low-carbon technology. Glob. Environ. Change 29, 444–458.
Baker, Lucy, Newell, Peter, Phillips, Jon, 2014. The political economy of energy transitions: the case of South Africa. New Polit. Econ. 19 (6), 791–818.
Barnham, Keith, Knorr, Kaspar, Mazzer, Massimo, 2012. Progress towards an all-renewable electricity supply. Nat. Mater. 11, 908–909.
Barrett, John, Owen, Anne, Taylor, Peter, 2018. Funding a Low Carbon Energy System: A Fairer Approach? UKERC, London.
Batterbee, J., 2018. Domestic Energy Services (Insight Report). Energy Technologies Institute, Loughborough(Available at: 〈http://www.eti.co.uk/insights/domestic-energy-services〉).
[BEIS]. Department for Business, Energy & Industrial Strategy, 2016. BEIS Electricity Generation Cost Report. (Available at: 〈https://www.gov.uk/government/publications/beis-electricity-generation-costs-november-2016〉).
[BEIS] Department for Business Energy and Industrial Strategy, 2017a. Industrial Strategy Building a Britain fit for the future. London. Cm 9528. (Accessed 9 May 2018).
[BEIS] Department for Business, Energy and Industrial Strategy, 2017b. Annual Fuel Poverty Statistics Report 2017 (2015 Data). (Accessed 9 May 2018). 〈https://www.gov.uk/government/statistics/annual-fuel-poverty-statistics-report-2017〉.
Brown, Donal, 2018. Business models for residential retrofit in the UK: a critical assessment of five key archetypes. Energy Effic. 11 (6), 1497–1517.
Büchs, Milena, Bahaj, AbuBakr, Blunden, Luke, Bourikas, Leonidas, Falkingham, Jane, James, Patrick, Kamanda, Mamusu, Wu, Yue, 2018. Sick and stuck at home – how poor health increases electricity consumption and reduces opportunities for environmentally-friendly travel in the United Kingdom. Energy Res. Social Sci. 44, 250–259.
Burger, Joanna, Gochfeld, Michael, 2012. A conceptual framework evaluating ecological footprints and monitoring renewable energy: wind, solar, hydro, and geothermal. Energy Power Eng. 4, 303–314.
Cambium Advocacy, 2015. Still Addressing the Poverty Premium. A Report for Citizens Advice Scotland by Cambium Advocacy, Edinburg(Available at 〈https://www.cas.org.uk/publications/still-addressing-poverty-premium〉).
[CCC] Committee on Climate Change, 2014. Meeting Carbon Budgets – 2014 Progress Report to Parliament. London.
Chatterton, T., Anable, J., Cairns, S., Wilson, R.E., 2018. Financial implications of car ownership and use: a distributional analysis based on observed spatial variance considering income and domestic energy costs. Transp. Policy 65, 30–39.
Cirell, Stephen, 2016. ESCOs: what they are, why they're important and how businesses can benefit. Available at 〈https://www.current-news.co.uk/blogs/escos-what-they-are-why-theyre-important-and-how-businesses-can-benefit〉.
Climate Change Act, 2008. Available at: 〈https://www.legislation.gov.uk/ukpga/2008/27/contents〉.
Creutzig, F., Fernandez, Blanca, Haberl, Helmut, Khosla, Radhika, Mulugetta, Yacob, Seto, Karen C., 2016. Beyond technology: demand-side solutions for climate change

mitigation. Annu. Rev. Environ. Resour. 41, 173–198.
Creutzig, Felix, Roy, Joyashree, Lamb, William F., Azevedo, Inês M.L., de Bruin, W.ändi Bruine, Dalkmann, Holger, Edelenbosch, Oreane Y., Geels, Frank W., Grubler, Arnulf, Hepburn, Cameron, Hertwich, Edgar G., Khosla, Radhika, Mattauch, Linus, Minx, Jan C., Ramakrishnan, Anjali, Rao, Narasimha D., Steinberger, Julia K., Tavoni, Massimo, Ürge-Vorsatz, Diana, Weber, Elke U., 2018. Towards demand-side solutions for mitigating climate change. Nat. Clim. Change 8, 260–271.
Davies, S., Finney, A., Hartfree, Y., 2016. Paying to be Poor: Uncovering the Scale and Nature of the Poverty Premium. University of Bristol Personal Finance Research Centre, Bristol. https://doi.org/10.13140/RG.2.2.11648.33280.(Retrieved from 〈http://www.bristol.ac.uk/media-library/sites/geography/pfrc/pfrc1615-poverty-premium-report.pdf〉).
DECC, 2013. An investigation of the effect of EPC ratings on house prices. Available at: 〈https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/207196/20130613_-_Hedonic_Pricing_study_-_DECC_template__2_.pdf〉.
Delina, L., Sovacool, B.K., 2018. Of temporality and plurality: an epistemic and governance agenda for accelerating just transitions for energy access and sustainable development. Curr. Opin. Environ. Sustain. 34, 1–6.
ETI, 2013. Transport: an affordable transition to sustainable and secure energy for light vehicles in the UK. Available at: 〈http://www.eti.co.uk/library/ldv-an-affordable-transition-to-sustainable-and-secure-energy-from-light-vehicles-in-the-uk〉.
Fell, Michael James, 2017. Energy services: a conceptual review. Energy Res. Social Sci. 27, 129–140.
Fuso Nerini, F., et al., 2017. Mapping synergies and trade-offs between energy and the sustainable development goals. Nat. Energy. https://doi.org/10.1038/s41560-017-0036-5.
Gabbatiss, Josh, 2018. Electric vehicles already able to cut greenhouse gas emissions by half. The Independent.
Geels, F.W., Sovacool, B.K., Schwanen, T., Sorrell, S., 2017. Sociotechnical transitions for deep decarbonisation. Science 357 (6357), 1242–1244.
Geels, F.W., Schwanen, T., Sorrell, S., Jenkins, K.E., Sovacool, B.K., 2018. Reducing energy demand through low carbon innovation: a sociotechnical transitions perspective and thirteen research debates. Energy Res. Social Sci. 40, 23–35.
Gerring, J., 2004. What is a case study and what is it good for? Am. Polit. Sci. Rev. 98 (2), 341–354.
Gerring, J., 2005. Case Study Research. Cambridge University Press, New York.
Gifford, Robert, 2011. The dragons of inaction: psychological barriers that limit climate change mitigation and adaptation. Am. Psychol. 66 (4), 290–302.
Gillard, R., Snell, C., Bevan, M., 2017. Advancing an energy justice perspective of fuel poverty: household vulnerability and domestic retrofit policy in the United Kingdom. Energy Res. Social Sci. 29, 53–61.
Graham-Rowe, Ella, Benjamin, Gardner, Abraham, Charles, Skippon, Stephen, Dittmar, Helga, Hutchins, Rebecca, Stannard, Jenny, 2012. Mainstream consumers driving plug-in battery-electric and plug-in hybrid electric cars: a qualitative analysis of responses and evaluations. Transp. Res. Part A: Policy Pract. 46 (1), 140–153.
Green, Geoff, Gilbertson, Jan, 2008. Warm Front, Better Health: Health Impact Evaluation of the Warm Front Scheme. Center for Regional, Economic, and Social Research, London(Available at 〈http://www.apho.org.uk/resource/view.aspx?RID=53281〉).
Hamamoto, Mitsutsugu, 2019. An empirical study on the behavior of hybrid-electric vehicle purchasers. Energy Policy 125, 286–292.
Hannon, Matthew J., Bolton, Ronan, 2015. UK local authority engagement with the energy service company (ESCo) model: key characteristics, benefits, limitations and considerations. Energy Policy 78, 198–212.
Hannon, Matthew J., 2015. Raising the temperature of the UK heat pump market: learning lessons from Finland. Energy Policy 85, 369–375.
Hawkins, T.R., Singh, B., Majeau-Bettez, G., Strømman, A.H., 2013. Comparative environmental life cycle assessment of conventional and electric vehicles. J. Ind. Ecol. 17 (1), 53–64.
Healy, N., Stephens, Jennie C., Malin, Stephanie A, 2019. Embodied energy injustices: unveiling and politicizing the transboundary harms of fossil fuel extractivism and fossil fuel supply chains. Energy Res. Social Sci. 48, 219–234.
Hielscher, S., Sovacool, B.K., 2018. Contested smart and low-carbon energy futures: media discourses of smart meters in the United Kingdom. J. Clean. Prod. 195, 978–990.
Hong, Sung H., Oreszczyn, Tadj, Ridley, Ian, for the Warm Front Study Group, 2006. The impact of energy efficiency refurbishment on the space heating fuel consumption in english dwellings. Energy Build. 38, 1171–1181.
Infield, David, 2007. A Road Map for Photovoltaics Research in the UK. Research Report (REF UKERC/RR/FSE/2007/001).
Jenkins, Kirsten, Heffron, R., McCauley, D., 2016a. The political economy of energy justice: a nuclear energy perspective. In: The Palgrave Handbook of the International Political Economy of Energy, pp. 661–682.
Jenkins, Kirsten, McCauley, Darren, Heffron, Raphael, Stephan, Hannes, Rehner, Robert, 2016b. Energy justice: a conceptual review. Energy Res. Social Sci. 11, 174–182.
Jenkins, Kirsten, Sovacool, B.K., McCauley, D., 2018. Humanizing sociotechnical transitions through energy justice: an ethical framework for global transformative change. Energy Policy 117, 66–74.
KPMG, 2015. UK solar beyond subsidy: the transition. London, UK.
Lambie-Mumford, H., Snell, C., Hunt, T., 2016. 'Heating or eating' and the impact of austerity. SPERI British Political Economy Brief No. 19. (Retrieved from 〈http://speri.dept.shef.ac.uk/wp-content/uploads/2016/02/SPERI-Brief-19-Heating-or-Eating-and-the-impact-of-austerity.pdf〉).
Lane, Ben, Potter, Stephen, 2007. The adoption of cleaner vehicles in the UK: exploring the consumer attitude–action gap. J. Clean. Prod. 15 (11–12), 1085–1092.
Lieberson, S., 1991. Small N's and big conclusions: an examination of the reasoning in comparative studies based on a small number of cases. Social Forces 70 (2), 307–320.
Lipson, M., 2017. Consumer Challenges for Low Carbon Heat. Insight Paper. Energy Technologies Institute, Loughborough(Available at: 〈http://www.eti.co.uk/insights/smart-systems-and-heat-consumer-challenges-for-low-carbon-heat/〉).
Lipson, M., 2018. How can People Get the Heat They Want at Home, Without the Carbon? Insight Paper. Energy Technologies Institute, Loughborough(Available at: 〈http://www.eti.co.uk/insights/how-can-people-get-the-heat-they-want-without-the-carbon〉).
Lorenzoni, Irene, Nicholson-Cole, Sophie, Whitmarsh, Lorraine, 2007. Barriers perceived to engaging with climate change among the UK public and their policy implications. Glob. Environ. Change 17 (3–4), 445–459.
Lowe, Robert, Chiu, Lai Fong, Oikonomou, Eleni, Gleeson, Colin, Love, Jenny, Wingfield, Jez, Biddulph, Philip, 2017. Case Studies Report from the RHPP Heat Pump Monitoring Campaign. UCL Energy Institute, London.
Mattioli, Giulio, 2016. Transport needs in a climate-constrained world. A novel framework to reconcile social and environmental sustainability in transport. Energy Res. Social Sci. 18, p118–p128.
May, Theresa, 2018. PM speech on science and modern Industrial Strategy: 21 May. Available at 〈https://www.gov.uk/government/speeches/pm-speech-on-science-and-modern-industrial-strategy-21-may-2018〉.
Milchram, Christine, Hillerbrand, Rafaela, Kaa, Geerten van de, Doorn, Neelke, Künneke, Rolf, 2018. Energy justice and smart grid systems: evidence from the Netherlands and the United Kingdom. Appl. Energy 229, 1244–1259.
Mitchell, William J., Christopher, E. Borroni-Bird, Burns, Lawrence D., 2010. Reinventing the Automobile Personal Urban Mobility for the 21st Century. MIT Press, Cambridge, MA.
Mullen, Caroline, Marsden, Greg, 2016. Mobility justice in low carbon energy transitions. Energy Res. Social Sci. 18 (2016), 109–117.
National Energy Action, 2017. The UK Fuel Poverty Monitor 2016–2017: a review of progress across the nations. Retrieved from 〈http://www.nea.org.uk/wp-content/uploads/2017/06/FPM_2017.pdf〉.
Newell, Peter, Mulvaney, Dustin, 2013. The political economy of the 'just transition'. Geogr. J. 179 (2), 132–140.
Nolden, Colin, Sorrell, S., Polzin, Friedemann, 2016. Catalysing the energy service market: the role of intermediaries. Energy Policy 98, 420–430.
Nolden, Colin, Sorrell, Steve, 2016. The UK market for energy service contracts in 2014–2015. Energy Effic. 9, 1405–1420.
Oceransky, Sergio, 2010. Fighting the enclosure of wind: indigenous resistance to the privatization of the wind resource in Southern Mexico. In: Abramsky, Koyla (Ed.), Sparking a Worldwide Energy Revolution: Social Struggles in the Transition to a Post-Petrol World. AK Press, Oakland, pp. 505–522.
Offer, G.J., Contestabile, M., Howey, D.A., Clague, R., Brandon, N.P., 2011. Techno-economic and behavioural analysis of battery electric, hydrogen fuel cell and hybrid vehicles in a future sustainable road transport system in the UK. Energy Policy 39 (4), 1939–1950.
OFGEM, 2017. Future Insights paper 4 –The futures of domestic energy consumption. 〈https://www.ofgem.gov.uk/publications-and-updates/ofgem-future-insights-series-futures-domestic-energy-consumption〉, (Accessed 1 June 2018).
ONS, 2017. Household expenditure on motoring for households owning a car, by gross income decile group. 〈https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/expenditure/adhocs/008150householdexpenditureonmotoringforhouseholdsowningacarbygrossincomedecilegroupukfinancialyearyearending2017〉, (Accessed 28 June 2018).
ONS, 2018. Dwelling stock statistics. 〈https://www.gov.uk/government/statistical-data-sets/live-tables-on-dwelling-stock-including-vacants〉, (Accessed 27 June 2018).
Park, J., Sovacool, B.K., 2018. The contested politics of the Asian atom: Peripheralisation and nuclear power in South Korea and Japan. Environ. Polit. 27 (4), 686–711.
Parkhill, K.A., Demski, C., Butler, C., Spence, A., Pidgeon, N., 2013. Transforming the UK Energy System: Public Values, Attitudes and Acceptability – Synthesis Report. UKERC, London.
Partridge, Tristan, Thomas, Merryn, Pidgeon, Nick, Harthorn, Barbara Herr, 2018. Urgency in energy justice: Contestation and time in prospective shale extraction in the United States and United Kingdom. Energy Res. Social Sci. 42, 138–146.
Reddy, K. Srikanth, Panwar, Lokesh Kumar, Kumar, Rajesh, Panigrahi, Bijaya Ketan, 2016. Distributed resource scheduling in smart grid with electric vehicle deployment using fireworks algorithm. J. Mod. Power Syst. Clean. Energy 4 (2), 188–199.
Robinson, Caitlin, Bouzarovski, Stefan, Lindley, Sarah, 2018. Getting the measure of fuel poverty': the geography of fuel poverty indicators in England. Energy Res. Social Sci. 36, 79–93.
Rockström, Johan, Gaffney, Owen, Rogelj, Joeri, Meinshausen, Malte, Nakicenovic, Nebojsa, Schellnhuber, Hans Joachim, 2017. A roadmap for rapid decarbonisation. Science 355 (6331), 1269–1271.
Seawright, J., Gerring, John G., 2008. Case selection techniques in case study research: a menu of qualitative and quantitative options. Polit. Res. Q. 61, 294–308.
Simcock, Neil, Mullen, Caroline, 2016. Energy demand for everyday mobility and domestic life: exploring the justice implications. Energy Res. Social Sci. 18, 1–6.
Sovacool, B.K., 2015. Fuel poverty, affordability, and energy justice in England: policy insights from the warm front program. Energy 93, 361–371.
Sovacool, B.K., Saunders, H., 2014. Competing policy packages and the complexity of energy security. Energy 67, 641–651.
Sovacool, B.K., Heffron, R.J., McCauley, D., Goldthau, A., 2016. Energy decisions reframed as justice and ethical concerns. Nat. Energy 16024, 1–6.
Sovacool, B.K., Kivimaa, P., Hielscher, S., Jenkins, K., 2017a. Vulnerability and resistance in the United Kingdom's smart meter transition. Energy Policy 109, 767–781.
Sovacool, B.K., Burke, M., Baker, L., Kotikalapudi, C.K., Wlokas, H., 2017b. New frontiers and conceptual frameworks for energy justice. Energy Policy 105, 677–691.

Sovacool, B.K., Noel, L.D., Zarazua de Rubens, G., Kester, J., 2019. Energy injustice and Nordic electric mobility: Inequality, elitism, and externalities in the electrification of vehicle-to-grid (V2G) transport,. Ecol. Econ. 157, 205–217.
Stewart, Alex, Hope-Morley, Alastair, Mock, Peter, Tietge, Uwe, 2015. Quantifying the Impact of Real-World Driving on Total CO_2 Emissions from UK Cars and Vans. Final Report for The Committee on Climate Change, Cambridge.
Stoknes, Per Espen, 2014. Rethinking climate communications and the “psychological climate paradox”. Energy Res. Social Sci. 1, 161–170.
Strielkowski, Wadim, Štreimikienė, Dalia, Bilan, Yuriy, 2017. Network charging and residential tariffs: a case of household photovoltaics in the United Kingdom. Renew. Sustain. Energy Rev. 77, 461–473.
Sundqvist, Thomas, 2004. What causes the disparity of electricity externality estimates? Energy Policy 32, 1753–1766.
Sweetnam, T., Fell, M., Oikonomou, E., Oreszczyn, T., 2018. Domestic demand-side response with heat pumps: controls and tariffs. Build. Res. Inf. 47 (4), 344–361.
Tran, Martino, Banister, David, Bishop, Justin D.K., McCulloch, Malcolm D., 2012. Realizing the electric-vehicle revolution. Nat. Clim. Change 2, 328–333.
Uddin, Kotub, Rebecca, Gough, Radcliffe, Jonathan, Marco, James, Jennings, Paul, 2017. Techno-economic analysis of the viability of residential photovoltaic systems using lithium-ion batteries for energy storage in the United Kingdom. Appl. Energy 206, 12–21.
von Stackelberg, K., Buonocore, J., Bhave, P.V., Schwartz, J.A., 2013. Public health impacts of secondary particulate formation from aromatic hydrocarbons in gasoline. Environ. Health 12, 13.
Wade, Faye, Hitchings, Russell, Shipworth, Michelle, 2016. Understanding the missing middlemen of domestic heating: Installers as a community of professional practice in the United Kingdom. Energy Res. Social Sci. 19, 39–47.
Walker, Gordon, 2008. Decentralised systems and fuel poverty: are there any links or risks? Energy Policy 36 (12), 4514–4517.
Walker, Gordon, 2012. Environmental Justice: Concepts, Evidence, and Politics. Routledge, London.
Walsh, Shannon, Stainsby, Macdonald, 2010. The smell of money: Alberta's tar sands. In: Abramsky, Koyla (Ed.), Sparking a Worldwide Energy Revolution: Social Struggles in the Transition to a Post-Petrol World. AK Press, Oakland, pp. 333–344.
Wells, Peter, 2015. Decarbonisation and Energy Efficiency: The Automotive Sector (2015). UKERC International Energy Summer School, Wyboston Lakes, UK.
Wilson, Charlie, Hargreaves, Tom, Hauxwell-Baldwin, Richard, 2017. Benefits and risks of smart home technologies. Energy Policy 103 (2017), 72–83.
Woodcock, James, Edwards, Phil, Tonne, Cathryn, Armstrong, Ben G., Ashiru, Olu, Banister, David, Beevers, Sean, Chalabi, Zaid, Chowdhury, Zohir, Cohen, Aaron, Franco, Oscar H., Haines, Andy, Hickman, Robin, Lindsay, Graeme, Mittal, Ishaan, Mohan, Dinesh, Tiwari, Geetam, Woodward, Alistair, Roberts, Ian, 2009. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. Lancet 374 (9705), 1930–1943.
Yenneti, Komali, Day, R., Golubchikov, Oleg, 2016. Spatial justice and the land politics of renewables: dispossessing vulnerable communities through solar energy mega-projects. Geoforum 76, 90–99.
Yin, R.K., 2014. Case Study Research: Design and Methods, 5th. edition. Sage Publications, Thousand Oaks, CA.